Did the Moon Form at 4.36 Ga?

CLAIRE L. MCLEOD[1]* AND ALAN BRANDON[1]

[1]Department of Earth and Atmospheric Sciences, University of Houston, Science and Research Building 1, Houston, TX, 77204, *clmcleod@central.uh.edu

Magma ocean crystallisation is an important stage of early planetary differentiation and evolution. Estimates for the timing of lunar magma ocean (LMO) crystallisation, and consequent formation of the lunar crust (ferroan anorthosites; FANS, and the Mg suite), is not well constrained with ages spanning from 4.57 Ga to 4.18 Ga[1,2,3,4]. More recent studies[5,6] on lunar crustal samples are consistent with a late *c*. 4.36 Ga age for the moon from Sm-Nd, Rb-Sr and Lu-Hf isotopes. The Sm-Nd isotopic systematics of KREEP samples and lunar mare basalts constrains the age of LMO crystallisation from 4.49 Ga to 4.31 Ga[7], while the Lu-Hf system suggest that the KREEP reservoir also formed *c*. 4.36 Ga[8]. The U-Pb ages of lunar zircons indicate a potentially older age for LMO solidification at *c*. 4.42 Ga[9].

To further examine LMO crystallisation and its relationship to the timing of lunar formation, a suite of mare basalts that span the range of petrologic types from the Apollo collection will be evaluated for their Sm-Nd systematics. High-precision ^{142}Nd/^{144}Nd to date indicate a closure age of *c*. 4.34±0.04 Ga for the Sm-Nd mare basalt source reservoirs[7,10]. With the additional new ^{142}Nd/^{144}Nd data presented here, we will test whether the previously obtained correlation with ^{143}Nd/^{144}Nd represents an isochron with an age *c*. 4.36 Ga, the implication of this being that the mantle source closure time for the basalts is consistent with a rapid LMO solidification following a late lunar formation time. Alternatively, if these new data do not lie on a coupled ^{142}Nd-^{143}Nd isochron, this would indicate multistage histories for their lunar mantle sources[11]. In the latter case, the coupled ^{142}Nd-^{143}Nd data for lunar basalts implies a more protracted differentiation history and are likely more consistent with an early formation time of the Moon.

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Magma-mixing processes recorded in compositionally zoned titanite from the Ross of Mull Granite, Scotland

G. W. MCLEOD[1]* AND T. J. DEMPSTER[2]

[1]Earth & Environment, University of Leeds, Leeds, LS2 9JT, UK (*correspondance: g.w.mcleod@leeds.ac.uk)
[2]Geographical and Earth Sciences, University of Glasgow, G12 8QQ, UK (tim.dempster@ges.gla.ac.uk)

Accessory minerals play a significant role in the control of trace element behaviour and consequently may be crucial in deciphering magma genesis and crystallization histories. Titanite is characterised by slow diffusion of trace elements, and as such may preserve magmatic zoning. The incorporation of REE and HFSE within titanite makes it ideal for assessing petrogenetic processes.

In plutonic environments the detail of petrogenesis is often lost as slow rates of cooling allow minerals to chemically re-equilibrate during sub-solidus diffusion. The Ross of Mull Granite displays a variety of plutonic level magma-mixing phenomena and represents an excellent site to test the potential of titanite to preserve geochemical fingerprints of its genesis. A textural and geochemical investigation of titanite from the pluton reveals that zoning in trace elements strongly correlates with field evidence of magma-mixing processes. Diorite enclaves contain a range of textures indicative of variable states of interaction with the host granite and suggest that a number of discrete mixing events have occurred, both prior to emplacement at the present level and in situ.

Titanites from both the enclaves and the host granite show compositional zoning dominated by fine-scale oscillatory types as well as major discontinuities linked to dissolution events associated with changes in titanite, and associated ilmenite, stability. The zones reflect growth during changing melt chemistry and correlate with variations in REE and HFSE. Introduction of fresh diorite magma into the granite host, and the subsequent mixing processes, induced compositional, temperature and oxygen fugacity changes to which titanite responded. Processes recorded by titanite zoning include; (i) homogenisation of crystal free melts; (ii) crystal transfer and scavenging between partially crystallised magmas; (iii) melt segregation and transfer from crystalline enclaves; and (iv) late-stage diffusive exchange. Titanite thus records both localised and distal mixing activity and is capable of revealing many otherwise hidden events within the magma chamber.

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